Journal of Stress Physiology & Biochemistry, Vol. 20, No. 4, 2024, pp. 63-79 ISSN 1997-0838

REVIEW

Review of the effects of seed priming for improving seed germination, seedling establishment and yield on several pulse crops

Urmita Garai[1] and Sabyasaci Patra[2]*

[1] *Research Scholar, Department of Botany, The University of Burdwan, Burdwan-713104, West Bengal, India*

[2] *Assistant Professor in Seed Technology, Department of Botany, The University of Burdwan, Burdwan-713104, West Bengal, India*

*E-Mail: sabya1983@gmail.com

Received May 24, 2024

Pulses are a unique type of crop due to their high content of vegetable protein, an important part of the human diet, and their major contribution to the cropping system through nitrogen fixation. A wide range of physiological deterioration that results in qualitative, quantitative, and economic losses occurs during the post-harvest storage of pulse crops. For pulse crop germination, growth, seedling establishment, and yield, the appropriate abiotic and biotic conditions are required. The article covers the seed priming approach, which can coordinate seed germination and increase vigor for better seedling establishment and productivity. Seed priming turns on metabolic pathways that break dormancy, prevent seeds from degrading, and boost overall resilience to biotic and abiotic stressors. The overall review provided in this paper describes how seed priming enhances pulse crop germination, seedling establishment, growth, and yield.

Key words: pulse crop, seed deterioration, seed priming, germination, yield

Optimisation of crop establishment is crucial to meet the rising demand for food. Therefore, methods for promoting crop establishment have been studied for a long time. To meet the world's food demand, pulses are an important crop. Because to its high protein content, it is often known as "poor man's meat" in developing countries. According to Kaisher *et al.* (2010), nitrogen-fixing bacteria found in the root nodule of pulse crops can improve soil fertility by fixing atmospheric nitrogen. Pulses make a suitable forage crop and green fodder (Mohammad *et al.*, 2012).

Environmental pollution and abiotic stresses are the major global issues for affecting seed germination, emergence, seedling vigour, and crop productivity (Carvalho *et al.*, 2011). Poor plant stand establishment and decreased yield of pulses in adverse environmental circumstances are considered to be the main causes of low pulse productivity. However, the formation of deep roots is a sign of speedy seed germination before the top soil layers have dried out and crusted, which comes from increased crop establishment and higher crop yield (Ashraf *et al.*, 2005).

The term "seed deterioration" refers to the "deteriorative alterations occurring over time that increase the seed's exposure to external challenges and reduce the seed's ability to survive." The quality of the seed gradually declines as the seed deteriorates. It is a natural process that affects seeds in which cytological, physiological, biochemical, and physical alterations reduce viability and ultimately end in seed death. Weak seedlings grow from germinated seeds, indicating degradation, which is seen as a decline in germination %. Losses in seed quality occur during field weathering, harvesting and storage (Farhadi *et al.,* 2012). Several biotic and abiotic factors influence quality, quantity, and economic losses. Severe post-harvest losses are caused by abiotic factors including temperature, moisture content, and relative humidity as well as biotic factors like insect pests and pathogens. Grain legumes are damaged during storage by a major pest like Bruchid (*Callosobruchus* spp.), which results in poor germination and, as a result, lower yield. (Chauhan *et al.,* 2002). Because there is no insect activity at moisture contents below 8%, seed moisture content below this level is considered as safe for insect activity. The ideal temperature range for storage insect activity is between 28 and 38 °C. Insect activity is considered unsafe at temperatures between 17 and 22 °C. The negative effects of these factors can be reduced by using fumigants and insecticides, but occasionally these chemicals also reduce seed vigour and viability, and some of them are hazardous to handle. However, fumigants which have been used successfully include methyl bromide, hydrogen cyanide, phosphine, ethylene dichloride and carbon tetrachloride in 3:1 mixture, carbon disulphide and naphthalene. Insecticides – used in seed storage include DDT, lindane and Malathion (Jyoti *et al.,* 2013). Additionally, there are a few storage fungi that are members of the Penicillium and Aspergillus genera. By generating poisonous compounds that kill seed cells, they cause seed degeneration. Mechanically damaged seed allow quick and easy access for mycroflora to enter the seed (Shelar *et al.*, 2008). To minimize the risk of fungi invasion, seeds have to be stored at low moisture content, low temperature, and relative humidity. Apart from these some abiotic factors also severely affect the stored seeds. It has been shown that with increasing temperature and moisture content, the rate of respiration of stored seeds increase (Chidananda *et al.,* 2014). The moisture content increase due to the water being released during respiration (around 0.409 g of H_2O released per gram of CO_2 evolution) (Rukunudin*et al.,* 2004). Moreover in the process of seedbed preparation for showing any crop seek sufficient resources that is time consuming and costly as well for re-sowing (Singh H *et al.,* 2015). It is crucial to embrace cost-effective and environmentally friendly practices like seed priming, low-input sustainable agriculture, conservation agriculture, etc. (Rakshit and Singh, 2018; Sarkar *et al.*, 2020). When seed priming addressed issues such as slow and uneven germination, low seed vigour, poor crop stand, biotic and abiotic stresses, poor product quality, etc., it attracted the attention of researchers and developed into the focus of extensive investigation and interest (Paparella *et al.*, 2015; Chatterjee *et al.*, 2018; Zulfiqar, 2021). Seed priming improves crop performance, promotes germination even in challenging conditions, and increases yield potential (Ajouri *et al.*, 2004; Ibrahim, 2016; Marthandan *et al.*, 2020). This method evolved as a workable tactic that safeguards plants against both biotic and abiotic stresses to mitigate the consequences of contemporary agriculture (Sarkar *et al.*, 2018). Under unfavourable conditions, such as in fragile ecosystems, the absolute performance of seed priming is more pronounced than under favourable conditions (Parera and Cantliffe, 1994).

Detrimental Effects of Seed Deterioration :

According to Mohammadi *et al.* (2011), Ghassemi-Golezani (2010), Astegar (2011), Farhadi (2012), and Biabani (2011) the following are some probable effects of deteriorative changes in seeds:

- Decreased percent germination;
- Reduction in vigor and viability;
- Degradation of cellular membranes and loss of permeability control;
- Increased solute leakage;
- Impairment of energy-yielding and biosynthetic mechanisms;
- Reduced biosynthesis and respiration;
- Reduced germination rate and early seedling growth;
- Reduced rate of plant growth and development;
- Reduced storage potential;
- Decreased growth uniformity;
- Increased susceptibility to environmental stresses, especially during germination, emergence, and early seedling development;
- Reduced tolerance under adverse conditions;
- Decreased yield;
- Decreased emergence percentage;
- Increased percentage of abnormal seedling;
- Loss of the capacity to germinate and
- Loss in seed weight.

Seed Priming and Mechanism of Seed Priming :

Seed priming is good technique to enhance seed performance, tolerant to stress and resistance to disease. Heydecker in 1973, first proposed the theory of seed priming. Seed priming is a technique in which pre showing seed treatment in water or in an osmotic solution to imbibe water to proceed the first stage of seed germination but prevent the radical protrusion through seed coat (Janmohammadi *et al.,* 2008). Fromearly evidence of seed priming is that it permits DNA replication, increase RNA and protein synthesis, enhances embryo growth, repairs deteriorated seed parts and reduces leakage of metabolites. The triphasic model of water uptake by dry orthodox seed consists of phase I (rapid water uptake) and phase II (lag phase with least water uptake or the activation phase) represent the most delicate phases for the process of germination and phase III begins (rapid water uptake followed by radicle emergence). The first two phases are crucial for successful seed priming treatment (Bewley, 1997). Although hydro-priming is the easiest and the most economical method, the non-controlled water uptake is the major disadvantage of it. Which may proceed until radicle protrusion if the process is not stopped at a precise moment before the phase III. Hence it is most crucial to determine the right amount of water required to hydrate seeds that initiates germination metabolism and carry out repair processes while preventing the radical emergence, i.e. the beginning of phase III?

The simplest and most effective method to synchronize seed germination, improve field emergence, and establish seeds in the farm is called seed priming, one of the several ways that can be used to maximize crop yield (Ghassemi-Golezani*et al.,* 2012 and Dalil, 2014).

There are different types of priming techniques according to Adetunji *et al.* 2021, viz.

Hydropriming: Soaking seed in water.

Halo priming: Soaking seed in salt solution.

Osmopriming:Soaking seeds in osmotic solution such as polyethylene glycol.

Solid matrix priming: Use of solid matrix as a carrier agent for osmotic solution.

Hormonal priming: Use hormone such as GA_3.

Redox priming: Priming with antioxidant compound such as glutathione, tocopherol.

Biostimulant priming: Coating the seeds with biological agent such as Bacteria.

Nano priming: Priming with phytosynthesized nanoparticles.

Magneto priming: Priming with the magnetic field.

EFFECT OF SEED PRIMING TREATMENTS ON DIFFERENT PULSE CROP SEEDS

Brief description of the effect of seed priming on several pulse crop seeds are as follows -

Effect of Seed priming on Lentil:

Seed priming is a simple technique to improve seedling establishment and crop performance in the field. There are many priming techniques which are very useful in rainfed areas. The effects of hydropriming, halopriming (1.5% KNO_3 and 15mS/cm NaCl) and osmopriming (PEG: Polyethylene glycol 6000 at -0.8MPa) were depicted by Ghassemi-Golezani *et al.* 2008, on seed invigoration and seedling establishment of lentil (*Lens culinaris* Medik). It has been shown that KNO_3 performs the highest germination percentage, although per day germination rate and seed vigour index are significantly high in case of hydroprimed seeds (Fig. 1).

The duration of priming is also important. Lentil (*Lens culinaris* Medik. cv. Kimia) seeds were primed with water for different time duration like 8 hr (P2) and 16 hr (P3) along with unprimed (P1) seeds (Ghasemi-Golezani *et al.,* 2013). Seeds primed with water for 8 hr (P2) before sowing gives better performance in plant height, biological and grain yields than unprimed (P1) and primed seeds for 16 hr(P3) (Fig. 2). Seed priming can induce some biochemical changes that initiate the early events of germination, but not permit the radical emergence. On the other hand priming beyond the optimal duration (8 hr) could be harmful due to damaging effects (Fig. 2).

Effect of Seed priming on Soybean:

To extend the seed vigour and viability in soybean [*Glycine max* (L.) Merill], through mid-storage invigoration technique, experiment was done by Patil *et al.,* 2017, using nine treatments consisting of different salts and botanicals consisting T1: control, T2: Water, T3: NaCl (10^{-3}M), T4: KI (10^{-3}M), T5: Na_2HPO_4 (10^{-3}M), T6: Iodine (0.1%), T7: $CaCl_2.2H_2O$ (1%), T8: Pongamia leaf extract (1%) and T9: custard apple leaf extract (1%) (Fig 3 & Fig 4)). Among the nine treatments superiority was observed in T6: Iodine (0.1%) followed by T7: $CaCl_2.2H_2O$ (1%) and then T2: Water, in case of seed germination percentage, seedling vigour index, dehydrogenase and alpha amylase production (Fig. 3 & Fig. 4). Thus the extension of storage potential of soybean seeds by an extra one month was observed by T6: Iodine (0.1%), T2: Water T7:$CaCl_2.2H_2O$ (1%).

Assefa *et al.,* (2010) reported that seed priming with GA_3 enhanced the emergence and germination rate of soybean.

Another study was conducted by Chavan *et al.,* 2014 to determine the importance of seed priming on field performance and seed yield of Soybean. There were two varieties viz., Phule Kalyani and JS-335 with six priming treatments viz., Control (unprimed seeds), Hydro-priming, KCl @10 ppm, $CaCl_2$*$2H_2O$ @ 0.5 %, KH_2PO_4 @ 50 ppm and GA_3 @ 20 ppm. It was concluded that soybean seeds positively responded to treatments of priming. However, priming generally improves the most parameters of soybean varieties through improving plant height, number of branches, number of pods per plant, number of seeds per pod, seed yield. The highest benefit of priming can be obtained from seeds primed with $CaCl_2$*$2H_2O$ (0.5%) treatment.

Effect of Seed priming on Mung Bean and Urd bean (black gram):

Mung Bean (*Vigna radiata* L.) is a major pulse crop in India, containing a good amount of protein, that is near about 25% protein, 1.3% fat, 60 % carbohydrate and 3.7% ash (Choudhary *et al.,* 2010; Hussain *et al.,* 2011). A study on effect of seed invigoration with different treatments, on seed germination, seedling growth and pod development was done by Kalubarmeand and Madakemohekar in 2019. Among the treatments urea showed better performance in days to germination, number of pods per plant, number of seeds per pod (Fig. 5). Although the pod length increased in KNO_3 treated seeds but it gave poor performance in germination and flowering (Fig. 5). However, it was clear that the seed germination, vigour and crop productivity can be improved by pre-sowing and invigoration treatments.

Another study was carried out by Gangaraju *et al.* in 2019, to assess the field emergence, speed of emergence and other growth parameters of Blackgram (*Vigna mungo* L. Hepper) with seven priming techniques of post harvest seeds. Seed priming consisted of T1: control, T2: hydropriming (hydration and drying at room temperature below 25°C, 12 hr), T3: iodine (100 mg iodine crystals through calcium carbonate, 2 g/kg), T4: GA_3 (hydration with 50 ppm GA_3 and surface drying at room temperature for 12 hr, T5: KNO_3, 0.5% (hydration and drying at room temperature, 12 hr), T6: KH_2 PO_4, 0.5% (hydration and drying at room temperature, 12 hr), T7: Chlorax (5g/kg) and the experiment was laid out in Randomized Complete Block Design (RCBD). All the treatments showed better result in compare to control (Fig. 6). Although seed priming with GA_3 is better among the other treatments in respect to plant height and field emergence.

Now a days bio priming has arised as a good sustainable technique in improving pulse crop production. According to Nawaz *et al.* 2021, bio priming were effective in alleviating detrimental effects of drought induced damaging impact in reducing crop growth and development. Bio priming significantly increases the field performances of Mung bean (*Vigna radiata* L.) (Fig. 7). It also regulate the level of antioxidant behaviour and improve nutrient uptake behaviour under terminal drought stress. The experiment was conducted using hydro priming, silicon priming and bio priming (Mixture strains of *Pseudomonas fluorescence* and *Rhizobium phaseoli*) along with a control (Fig. 7). Among these different priming techniques bio priming is helpful for better performance of mung bean in terms of plant height, no. of leaves, root length, no. of nodules per plant, pod bearing branches per plant, pods per plant, grains per pod, pod size along with plant tolerance against terminal drought stress (Fig. 7). This may be due to strong antioxidant defence system and better nutrient uptake behaviour in bio priming under terminal drought stress.

Application of micronutrients like Zn causes improvement of grain and biological yield which is an indication of improvement of yield and growth related parameters (i.e. plant height, no of grains per pod, 100 grain weight, grain yield per plant, biological yield per plant, harvest index) (Fig. 8). Seeds priming with 0.01M Zn performs better than 0.05M Zn priming and hydro priming on different yield attributes and grain zinc content of mung bean(*Vigna radiata* L. Wilczek) (Haider *et al.,* 2020)

Effect of Seed priming on Chick pea:

Among different concentration of micronutrient like Zn plays important role in seed development.Seed priming is a low-cost strategy that involves soaking seeds in a solution containing Zn for an appropriate period of time before redrying and sowing seeds (Rehman *et al.*, 2012). It can be applied by foliar sprays, soil application or seed priming (Farooq *et al.,* 2012, Haider*et al.,* 2018). A study was conducted by Ullah *et al* in 2019 to optimize the different concentration of zinc seed priming that improve stand establishment, tissue Zn concentration and seedling growth of chickpea (*Cicer arietinum* L.) (Fig. 9). Higher zinc concentration inhibit the germination of chickpea, but seed priming at 0.001M Zn concentration sufficiently enhance the emergence/enhancement and seedling development (Fig. 9). At higher concentration of Zn, toxicity increase inside the seed, which also act as heavy metal (Fig. 9).

Another field experiment on chickpea (*Cicer arietinum* L.) variety PBG 1 was conducted by Singh *et al.*, 2014 during the Rabi seasons in 2009-10 and 2010-11 at Punjab Agricultural University Regional Research Station for Kandi Area, Ballowal Saunkhri to study the effect of seed priming with molybdenum (Mo). Seed priming with 250, 500 and 750 ppm solution of molybdenum and untreated control were laid out in randomized complete block design with four replications. Plant height, number of pods/plant, test weight, seed yield, straw yield and rain water use efficiency were significantly increased with the increasing concentration of Mo seed priming up to 500 ppm. Dry weight of root nodules increased up to 750 ppm of Mo. It was clearly visible that all the levels of Mo were significantly superior to untreated control for most of the characters. Seed priming with 500 ppm of Mo showed 18.9% higher seed yield over control. Higher net returns and Benefit Cost ratios were also observed in case of 500 ppm Mo treatment.

A field experiment was conducted by Gupta and Singh in 2012 in SKUAST-Jammu in Inceptisols to find out the effects of seed priming on chickpea. The treatments consisted of seed priming in water for 8 h. The experiment was reported the plant height, nodule dry weight, seed index, dry matter accumulation, yield and yield attributes of chickpea. The results showed that the growth parameters of chickpea were significantly affected by seed priming. Soaking chickpea seeds in water for 8 h significantly influenced plant height and nodule dry weight in comparison to unsoaked seeds. Seed priming significantly affected dry matter accumulation at various time intervals and at harvest time. Seed priming, on an average, yielded 22.1% higher dry matter accumulation at different time intervals after sowing. Although at harvest, seed priming registered statistically higher pods/plant, seeds/pod, grain and biological yield which were 27.0, 11.9, 23.1 and 22.0% higher over no seed priming.

Effect of Seed priming on Cow pea:

Effect of seed priming on germination properties and seedling establishment of cowpea (*Vigna sinensis*) was done by Eskandari *et al.,* in 2011. Seeds were primed with KNO_3, 1.5 % NaCl 0.8% and distilled water for 8, 12, 16 hours (Fig. 10). Significant differences in percentage rate and seedling emergence among seed treatment was observed (Fig 10). Hydroprimed seeds and seeds primed with NaCl show higher seedling emergence percentage than those with KNO_3 primed and unprimed seeds (Fig. 10). The highest rate of seedling emergence was observed in primed seeds with water with 16 hr duration (Fig. 10).

Another study by Singh *et al.*, 2014 which was conducted to study the effect of osmo-priming duration on germination, emergence and early growth of cowpea in Nigeria. Three treatment consisted osmo-priming duration (soaking in 1 % KNO_3 salt for 6, 8 and 10 hrs) and one hydro-primed control (10 hr). The results revealed that osmo-priming with KNO_3 for different durations were superior to unprimed treatment in term of seed germination, emergence, plant height and dry matter accumulation in cowpea. However, both osmo primed and hydro-primed seeds increased performance of cowpea. However, osmo-priming with 1 % KNO_3 salt solutionfor 6 hours could result in greater seed germination and seedling height than hydro-priming.

Effect of Seed priming on Pigeon pea:

In the tropics and subtropics Pigeon pea [*Cajanus cajan* (L.) Millsp.] is one of the major grain legume crops, endowed with several unique characteristics. Pigeon pea keeps an important place in the cropping system adopted by small farmer in a number of developing countries, which occupies 6.5 per cent of the world's total pulses area and contributes 5.7 per cent to the total pulse production. India is one of the largest producer of pigeon pea accounting about 64 per cent of total world production followed by Myanmar (22 per cent) and Malawi (6 per cent). Like other pulses, it is grown under rain fed condition and about 96 per cent of pigeon pea area is unirrigated.

Experiment was conducted by Sajjan *et al.,* 2017 in the Seed Testing Laboratory during 2013 and 2014 at RARS, UAS Campus, Vijayapur, Karnataka State. The seeds of [*Cajanus cajan* (L.) Millsp.] were primed by soaking in different leaf extracts and chemical solution for one hour and then decanted the extracts and seeds were air dried under the shade to bring back to their original moisture content and used for seed quality studies. The results showed that seed germination was significantly influenced by age of the seeds and its interaction with botanicals and chemicals (Fig. 11). Among the treatments, botanicals like Prosopis leaf extracts @ 2per cent was recorded higher seed germination followed by Pongamia leaf extract @ 2per cent. Whereas, in chemicals higher germination was seen in seeds treated with KNO_3@ 0.5 per cent but at par with $CaCl_2$. $2H_2O$ @ 2 per cent (Fig. 11). Lower germination was obtained with control or water soaked seed (Fig. 11). Overall, the investigation indicated that, seed priming with 2.0 per cent Prosopis leaf extract for one hours soaking enhanced the seed and seedling quality (shoot length, root length and vigour index) characters and hence it could be adopted as a pre-sowing seed priming treatment in pigeon pea (Fig. 12, 13 & 14).

Apart from that, in pigeon pea seed treatment with $CaCl_2$ or KNO_3 generally exhibited improvement in proteins, free amino acid and soluble sugars during germinating under salt stress (Verma and Srivastava, 1998).

METHODS

The scientific information on seed priming of pulse crops were obtained from various online bibliographic databases such as Science Direct, Google Scholar etc. The articles with rigorous quality were selected for the review. Relevant articles published before 2024 were collected using the key words pulse seed germination, seed priming etc.

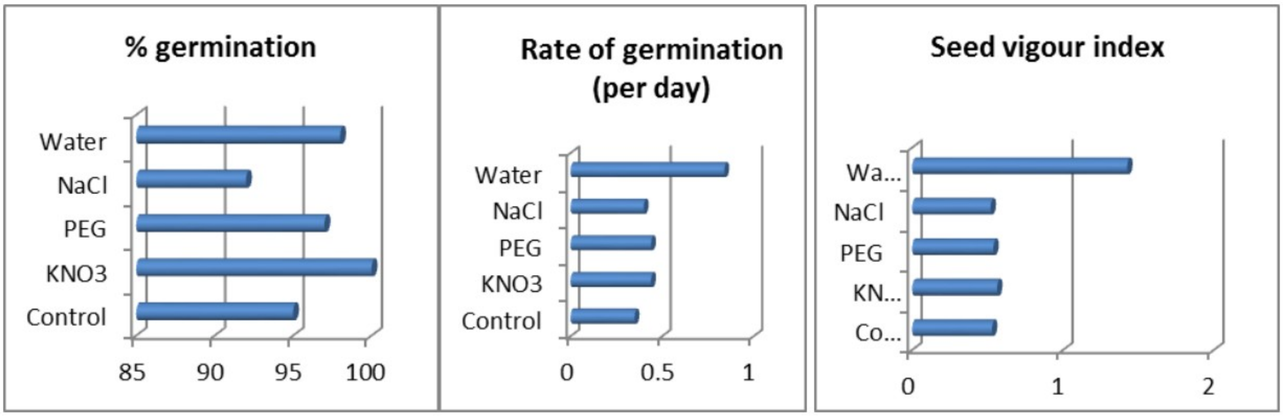

Figure 1. Effect on percent germination, per day germination rate and seed vigor index of different priming techniques in Lentil seed (*Lens culinaris* Medik) by Ghassemi-Golezani *et al.,* 2008.

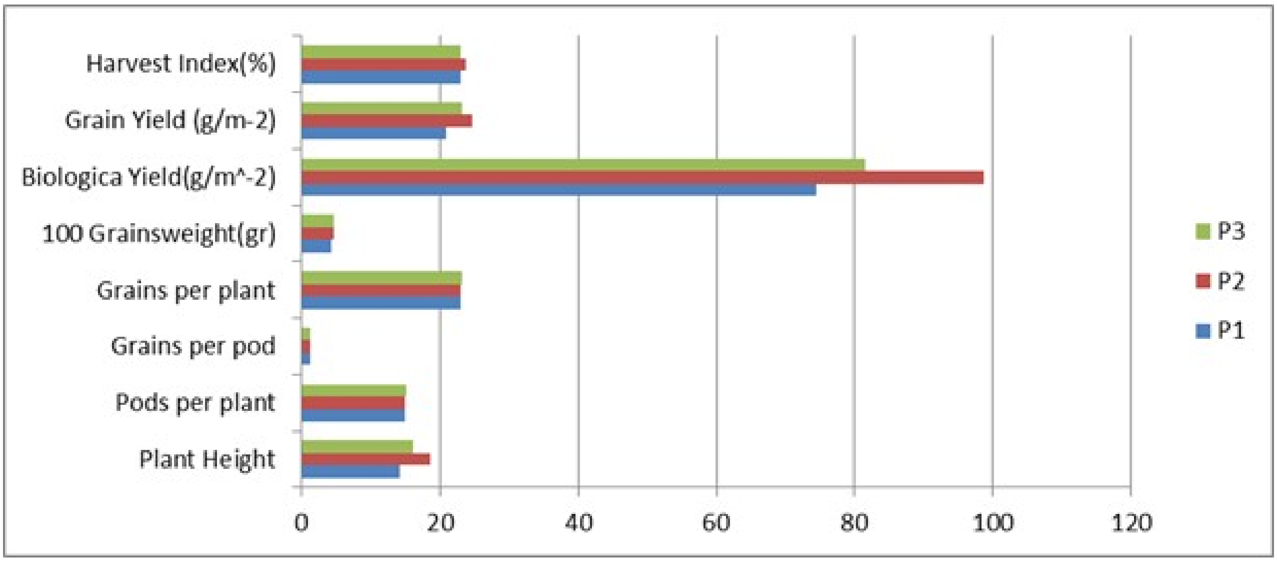

Figure 2. Effect on yield and yield attributes of hydro priming P2 for 8 hr and P3 for 16 hr respectively and non- primed (P1) seeds in Lentil (*Lens culinaris* Medik) by Ghasemi-Golezani *et al.* 2013.

Note : P2 & P3 are denoted for Hydro priming and P1 for Non-primed.

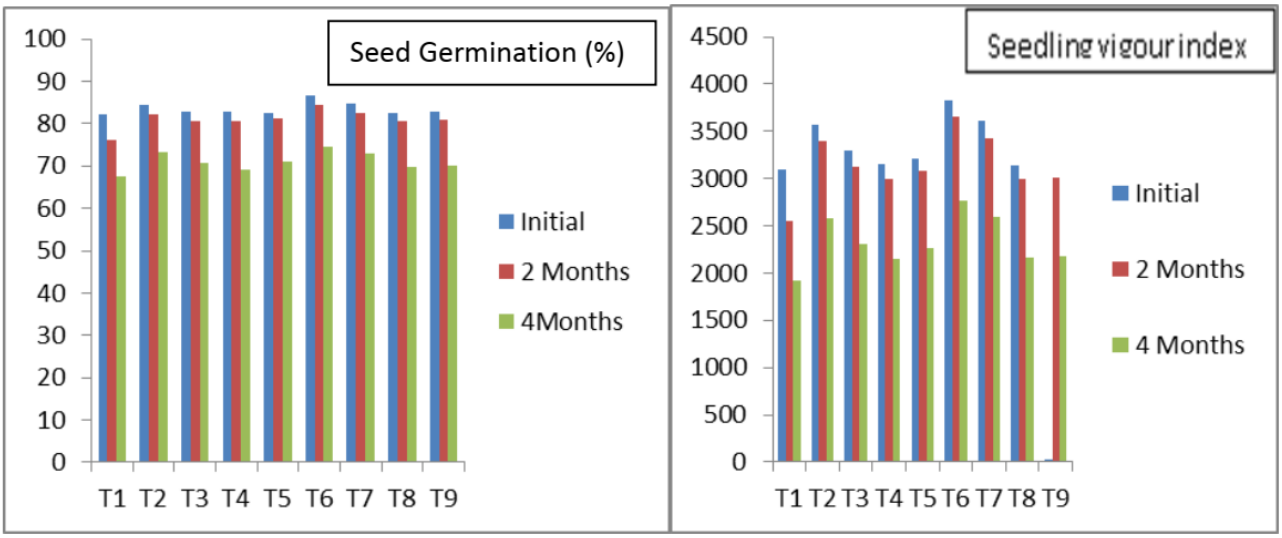

Figure 3. Effect of T1:control, T2: Water, T3: NaCl (10^{-3}M), T4: KI (10^{-3}M), T5: Na_2HPO_4 (10^{-3}M), T6: Iodine (0.1%), T7:$CaCl_2.2H_2O$(1%), T8: Pongamia leaf extract (1%) and T9: custard apple leaf extract (1%) on seed germination percentage and seedling vigor index in soybean [*Glycine max* (L.) Merill], through mid-storage invigoration technique by Patil *et al.,* 2017.

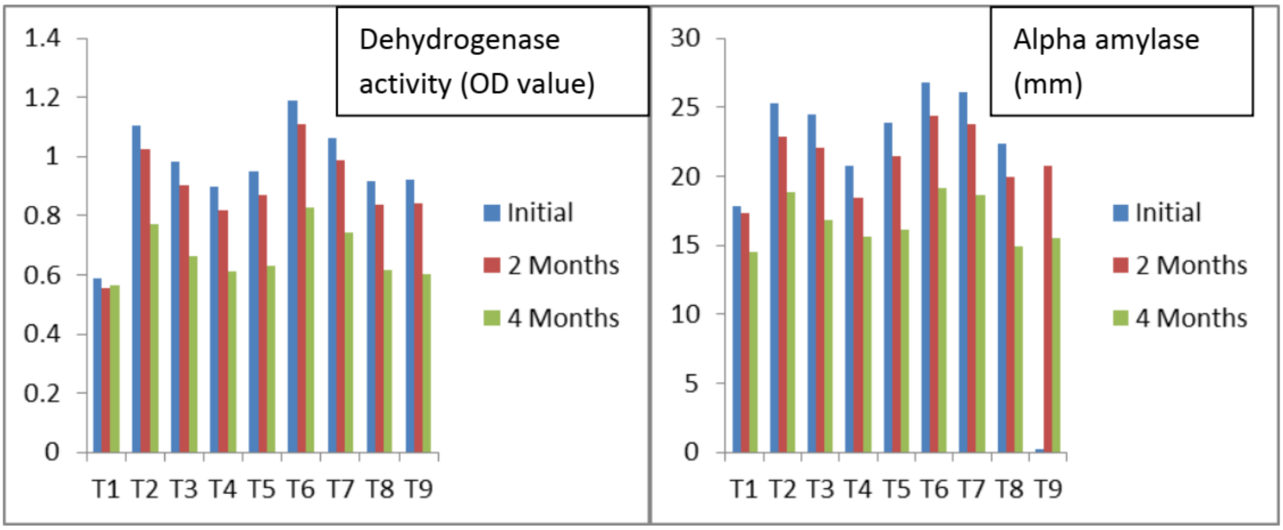

Figure 4. Effect of T1:control, T2: Water, T3: NaCl (10^{-3}M), T4: KI (10^{-3}M), T5: Na_2HPO_4 (10^{-3}M), T6: Iodine (0.1%), T7:$CaCl_2.2H_2O$(1%), T8: Pongamia leaf extract (1%) and T9: custard apple leaf extract (1%) on dehydrogenase and alpha amylase activity in soybean [*Glycine max* (L.) Merill], through mid-storage invigoration technique by Patil *et al.,* 2017.

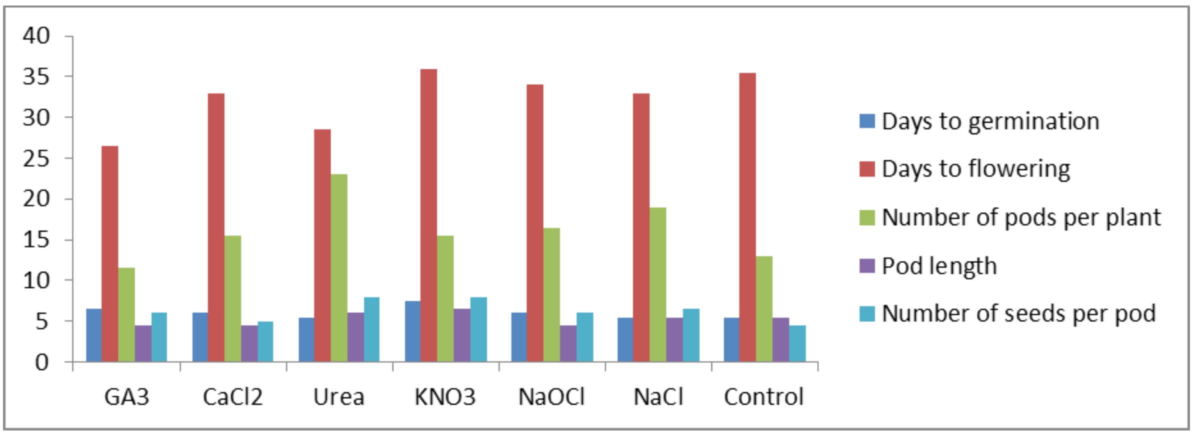

Figure 5. Effect of different treatments (GA_3, $CaCl_2$, Urea, KNO_3, NaOCl, NaCl) on different morphological parameters of Mung Bean (*Vigna radiata* L.) by Kalubarmeand and Madakemohekar, 2019.

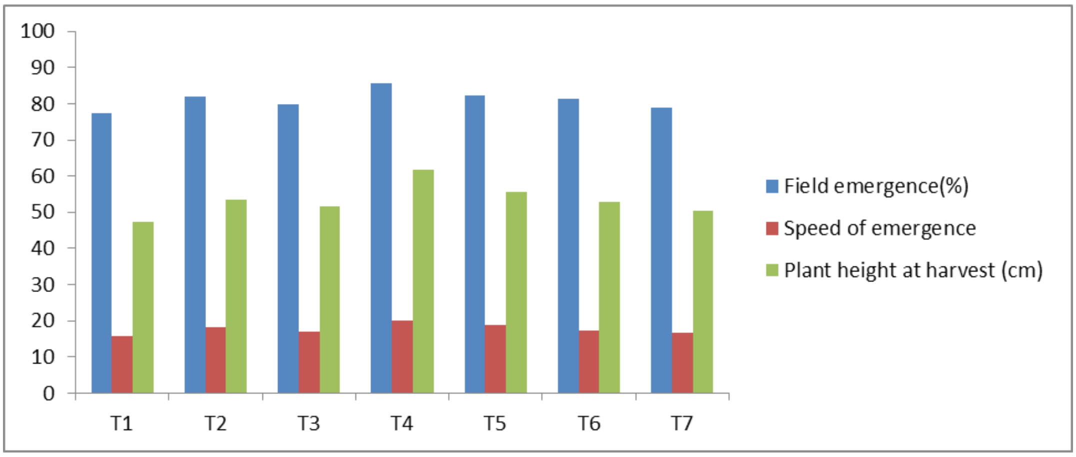

Figure 6. Effect of seven priming techniques T1: control, T2: hydropriming (hydration and drying at room temperature below 25°C , 12 hr), T3: iodine (100 mg iodine crystals through calcium carbonate, 2 g/kg), T4: GA_3 (hydration with 50 ppm GA_3 and surface drying at room temperature for 12 hr, T5: KNO_3, 0.5% (hydration and drying at room temperature, 12 hr), T6: KH_2 PO_4 , 0.5% (hydration and drying at room temperature, 12 hr), T7: Chlorax (5g/kg) of post harvest seeds of Blackgram (*Vigna mungo* L. Hepper) by Gangaraju *et al.* 2019

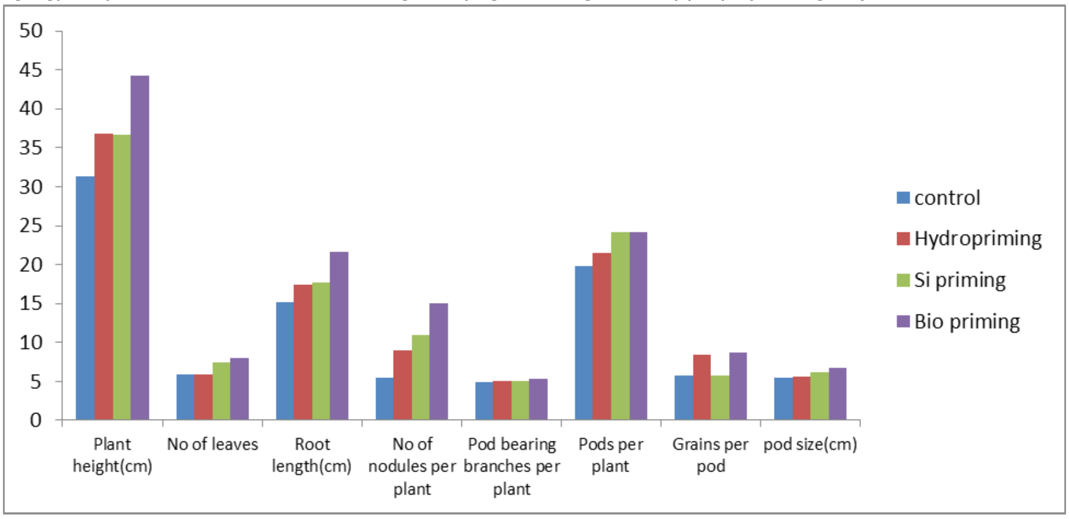

Figure 7. Effect of hydro priming, Si priming (Mixture strains of *Pseudomonas fluorescence* and *Rhizobium phaseoli*) and bio priming on different yield attributes of mung bean (*Vigna radiata* L.) on terminal drought stress by Nawaz *et al.*, 2021.

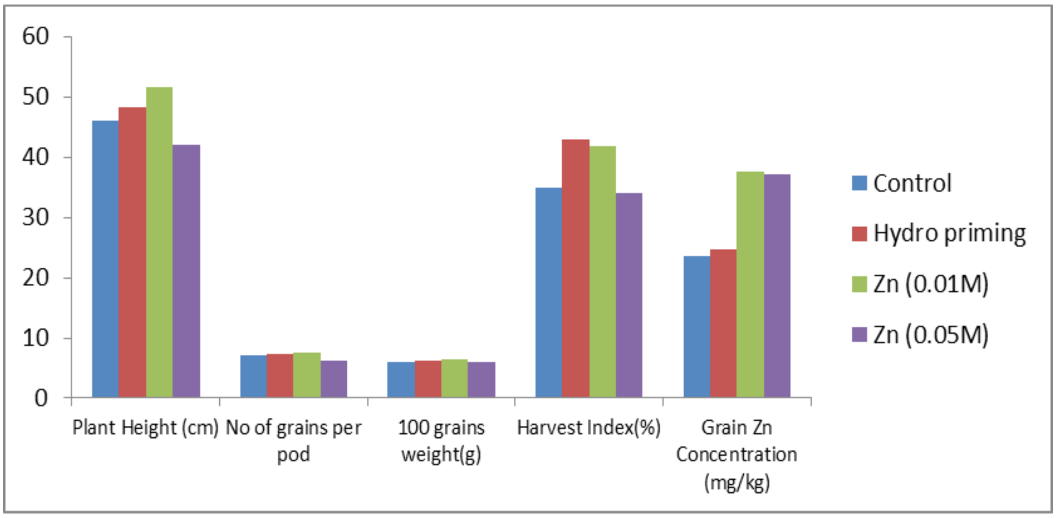

Figure 8. Effect of zinc seed priming on different yield attributes and grain zinc content in mung bean (*Vigna radiate* L.Wilczek) by Haider *et al.,* 2020.

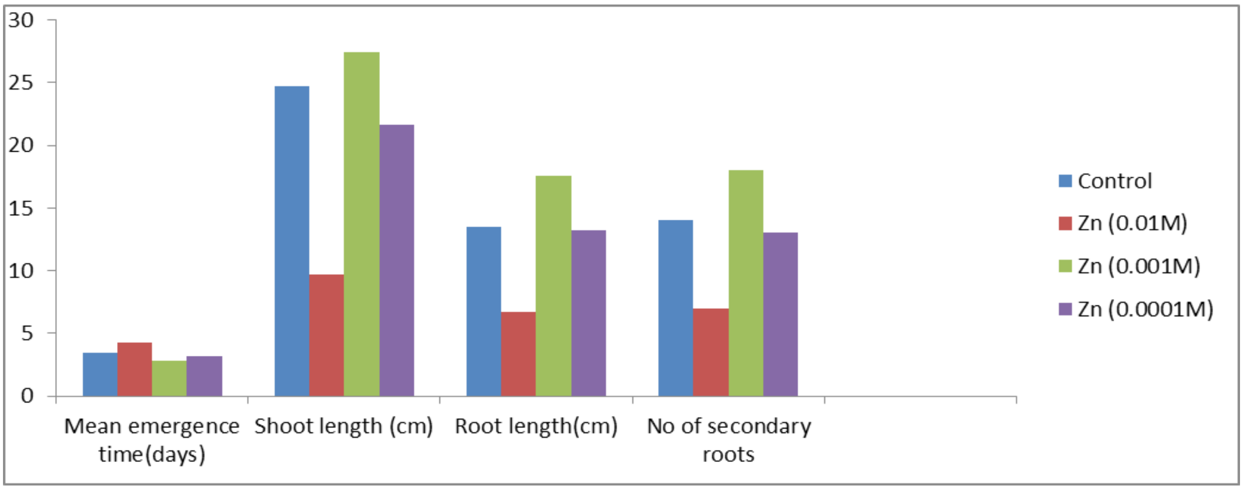

Figure 9. Effect of different concentration of Zn seed priming on seedling emergence, seedling growth and no of secondary roots in Chickpea (*Cicer arietinum* L.). (sand filled pot experiment) by Ullah *et al.* 2019.

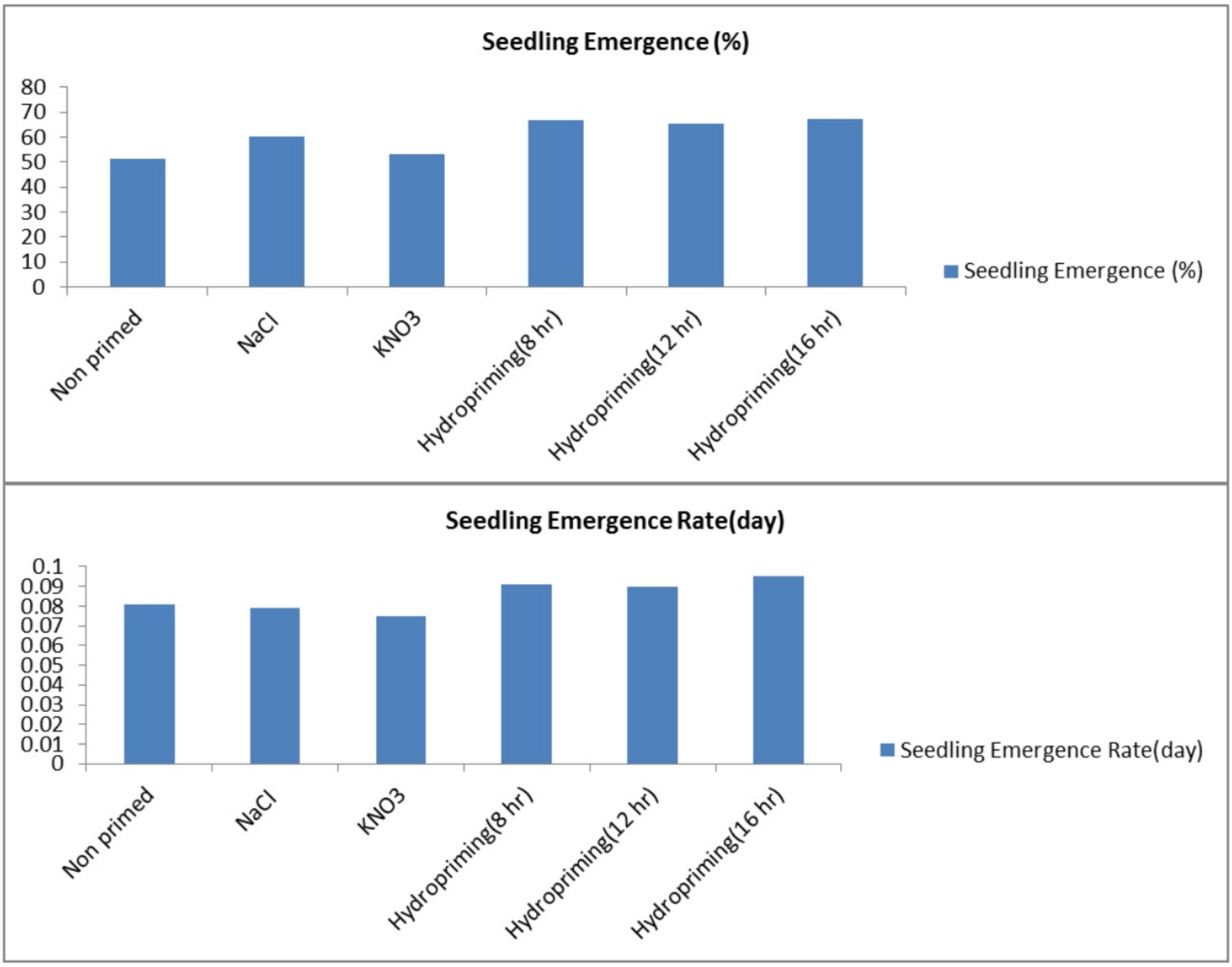

Figure 10. Effect of different seed priming with KNO_3 1.5 %, NaCl 0.8% and distilled water for 8, 12, 16 hours on seedling emergence percentage and seedling emergence rate (day) of cowpea (*Vigna sinensis*). by Eskandari *et al.*, 2011.

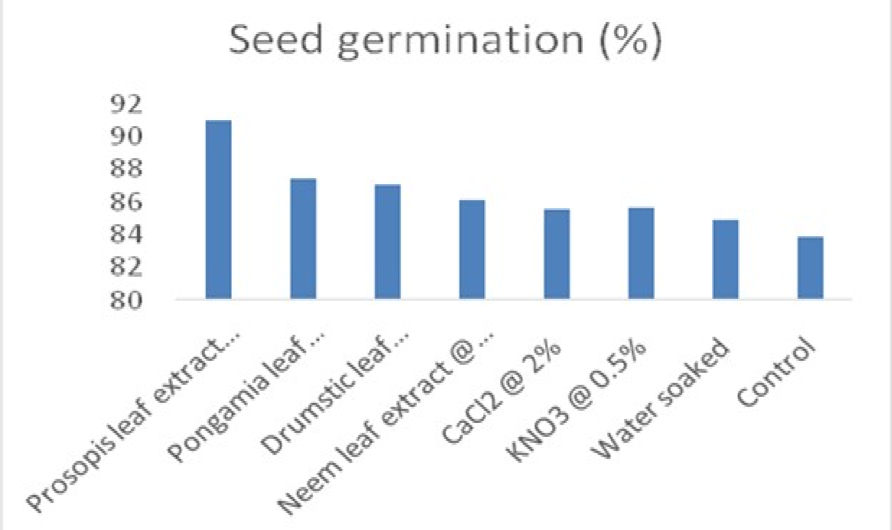

Figure 11. Effect of primed seed by soaking in 2 % extract of prosopis leaf, pongamia leaf, drumstic leaf and neem leaf, chemical solution like $Cacl_2$ @ 2%, KNO_3@ 0.5%, and $2H_2O$ @ 2% soaked and non primed (control) on germination percentage of Pigeon pea [*Cajanus cajan* (L.) Millsp.] by Sajjan *et al.,* 2017.

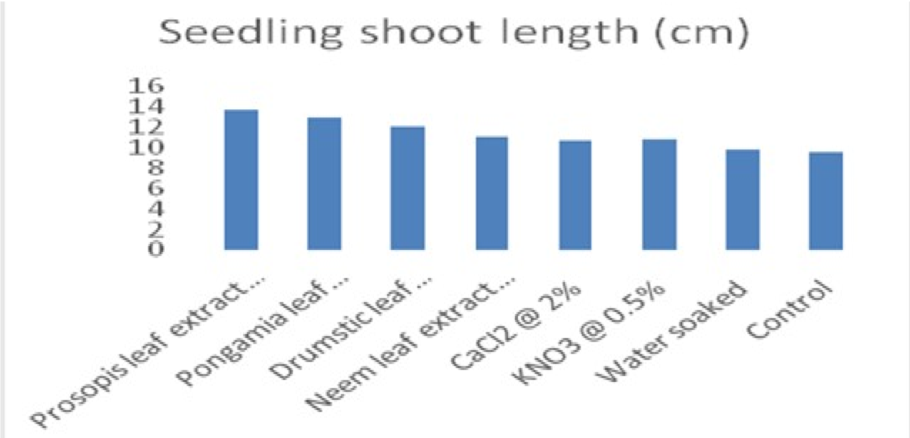

Figure 12. Effect of primed seed by soaking in 2 % extract of prosopis leaf, pongamia leaf, drumstic leaf and neem leaf, chemical solution like $Cacl_2$ @ 2%, KNO_3@ 0.5%, and $2H_2O$ @ 2% soaked and non primed (control) on seedling shoot length of Pigeon pea [*Cajanus cajan* (L.) Millsp.] by Sajjan *et al.,* 2017.

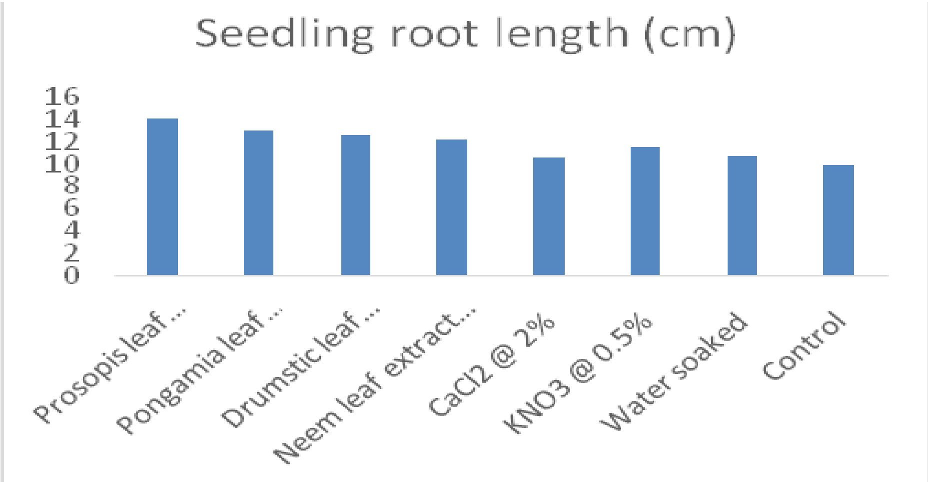

Figure 13. Effect of primed seed by soaking in 2 % extract of prosopis leaf, pongamia leaf, drumstic leaf and neem leaf , chemical solution like $Cacl_2$ @ 2% ,KNO_3@ 0.5% , and $2H_2O$ @ 2% soaked and non primed (control) on seedling root length of Pigeon pea [*Cajanus cajan* (L.) Millsp.] by Sajjan *et al.,* 2017.

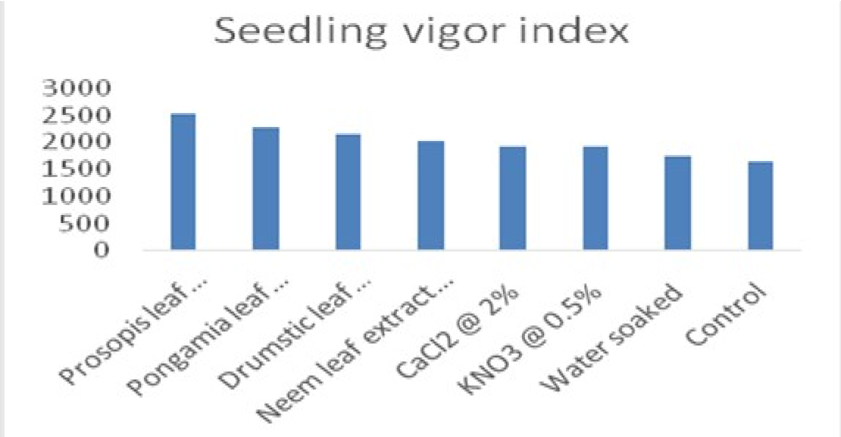

Figure 14. Effect of primed seed by soaking in 2 % extract of prosopis leaf, pongamia leaf, drumstic leaf and neem leaf, chemical solution like $CaCl_2$ @ 2%, KNO_3@ 0.5%, and $2H_2O$ @ 2% soaked and non primed (control) on seedling vigour of Pigeon pea [*Cajanus cajan* (L.) Millsp.] by Sajjan *et al.,* 2017.

RESULTS AND DISCUSSION

Seed priming has been proved by different researchers to improve early seedling growth and stand establishment (Arif *et al.*, 2005). The priming concept usually a type of seed invigoration, all involving controlled hydration of seeds (Farooq *et al.*, 2006). The seed priming technique is mainly used to improve the overall post-harvest performance of seed (Mirmazloum *et al.*, 2020) including longevity (Chandra *et al.*, 2019) and ability to combat with unfriendly environmental conditions (Ashraf *et al.*, 2018). Seed priming enhances seed germination in three phases (Bewley *et al.*, 1997) which are imbibition, germination, and growth (Waqas *et al.*, 2019). The first phase, imbibition is characterised by rapid water uptake owing to low seed water potential, respiratory activity and protein synthesis, through existing DNA and mRNA, are promoted. Phase II, germination is a lag phase involving the initiation of various physiological functions relating to germination, including protein and mitochondria synthesis, degradation of stored food and reorganisation of cellular membranes, and helps in the commencement of Phase III. Phase IIIis the stage of radicle protrusion and growth of the seedling, which is also called the growth phase (Waqas *et al.*, 2019, Varier *et al.*, 2010). The key determinant of seed priming is the controlled uptake of water up to Phase II, prior to radicle emergence (Waqas *et al.*, 2019, Varier *et al.*, 2010), which allows the physiological events, such as damaged DNA and mitochondria repair (Bewley *et al.*, 1997). Priming duration mayvary from less than 24 h (Cantliffe *et al.*, 1981) to days (Bradford *et al.*, 1990) or weeks (Khan *et al.*, 1980) depending on cultivars, species, and seed lot (Taylor *et al.*, 1988). Phase II is more sensitive to various environmental factors than Phase III. For this reason, primed seeds that have undergone Phase II may be able to germinate better than unprimed seeds under suboptimal conditions (Waqas *et al.*, 2019).

During priming, as the embryo expands, the endosperm compresses (Liptay *et al.,* 1993). According to Lin Y *et al.* (1993), the compressive stress of the embryo and hydrolytic activity on the endosperm cell walls can deform the tissues, leading to a loss of flexibility upon dehydration, which creates free space and promotes root protrusion after rehydration. That may be the reason of fastest rate of germination in hydropriming (Fig. 1 and Fig. 8). Although the water uptake, in case of halo- and osmopriming, was slower and resulted in less advanced metabolic processes and slower germination (Fig 1) as limited water were available. Although, differences in germination percentage among seeds treated with KNO_3, water and PEG were not significant, the highest germination percentage was obtained with KNO_3 priming (Fig. 1). This is evident from here that there is no toxic effect of KNO_3, due to ion accumulation in the embryo. Pre-sowing treatment with inorganic salts not only promotes seed germination of most crops, but also stimulates later growth, metabolic processes and, hence, ultimate crop production.

The superiority of hydro-priming for 8 hours in improving grain yield per unit area mainly resulted from higher plant height and consequently biological yield, compared with P1 and P3 treatments (Fig. 1). Therefore, the resultant effects of priming depends on duration of seed soaking, beyond which it could be damaging to the seed or seedling (Ghassemi-Golezani *et al.,* 2008b). Thus, optimal time of hydro-priming for lentil seeds is about 8 hours, which can be successfully applied to enhance grain yield of lentil in the field.

McDonald (1999) suggested that the improvement in germination is influenced by pre-soaking of seeds due to activation of repair mechanisms and metabolic process which occur during water absorption. Iodine performed better (Fig. 2) due to its involvement in repair and control mechanism of membrane damage incurred during post harvest storage. For the property of iodine which allow to rapidly pass into the vapour phase and is also characterised by its great affinity for double bonds of unsaturated lipid constituents of the cell (Gopa and Mukherjee, 1984). Lower lipid peroxidation and lower free fatty acid formation in treated seeds particularly with iodine (Fig. 2) over untreated seeds suggest that invigoration treatment may partly play role in scavenging free radical formed during dry storage (McDonald, 1999).

Some earlier reports suggest that seed treated with bio-priming and Si priming before sowing may lead to vigorous production of germination metabolites, better root system development, faster RNA, DNA and protein synthesis, stimulate the seed biochemical processes for an earlier breakdown of seed dormancy (Ahmad *et al.* 2011). Moreover, bio-priming and Si-priming (Fig. 5) help in improving the early emergence and seedling establishment may be due to efficient utilization of resources including's NP contents in the soil during the entire growing season of the crop under terminal drought stress condition (Kumar and Sharma 2009).

Seeds primed with Zn at different levels achieved superior stand establishment, seedling growth, grain yield (Fig. 6 and 7) and enhanced the grain Zn contents in comparison to those grown through un-primed seed that had poor stand establishment, seedling growth and seed yield. However, involvement of Zn might be attributed to the photosynthesis, cell division, protein synthesis, retaining membrane structure and providing the resistance against pathogen (Sarwar 2011). That enhancement might be due to Zn availability required for the synthesis of lipids, protein, carbohydrates and nucleic acid (Khan *et al.,* 2002) that are necessary for the superior growth and development of seedlings. Arif *et al.,* 2008 reported on the basis of a field experiment in Peshawar, Pakistan, that priming improved the seed establishment in soybean which might be due to the completion of pre germination metabolic activities earlier which makes the seed ready for radical protrusion.

CONCLUSION

This leads to the conclusion that seed priming considerably increases pulse productivity. In order to increase seed vigour, germination, improved crop establishment, root growth, growth, and yield attributes, several seed priming treatments are utilized in pulse crops. Seed priming promotes enhanced pulse productivity by improving all these characteristics. Improvement of seed quality by physiological seed priming is a simple, easy and inexpensive approach to enhance the seed performance and productivity. This is important for resource-poor farmers as a low- or no-cost technology and requires few external inputs. Currently these techniques are being adopted mostly for obtaining high value and good quality seeds. Hydropriming is a most powerful and practical technique to the farmers which is easily available, less labour cost and disposal concern in comparative to other priming methods. In drought prone and rainfed areas, farmers can practice this technique to increase the stress tolerance of pulse seeds.

ACKNOWLEDGEMENTS

We appreciate CRSMF (Crop Research and Seed Multiplication Farm), Burdwan University for providing several facilities like computer, internet etc. for searching web based information and necessary data to prepare the review Paper

CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

REFERENCES

Adetunji, A. E., Adetunji, T. L., Varghese, B., Sershen, &Pammenter, N. W. (2021). Oxidative stress, ageing and methods of seed invigoration: an overview and perspectives. *Agronomy*, *11*(12), 2369.

Ahmad M., Zahir Z A., Asghar H N. (2011). Inducing salinity tolerance in mung bean through rhizobia and plant growth promoting rhizobacteria containing 1-aminocyclopropane 1-carboxylatedeaminase; *Canadian Journal of Microbiology*, 57, 578–589.

Ajouri A., Asgedom H., Becker M. (2004). Seed priming enhances germination and seedling growth of barley under conditions of P and Zn deficiency. *J. Plant Nutr. Soil Sci.* 167, 630–636.

Arif M, Jan M T, Marwat B K and Khan A M; (2008) Seed priming improves emergence and yield of soybean;; *Pak J Bot*. 40: 1169-77.

Arif M, S Ali, A Shah, N Javid, and A Rashid; (2005) Seed priming maize for improving emergence and seedling growth. *Sarhad Journal of Agriculture* 21: 539–543.

Ashraf MA, Akbar A, Askari SH, Iqbal M, Rasheed R, Hussain I; (2018) Recent advances in abiotic stress tolerance of plants through chemical priming: An overview. In Advances in Seed Priming; Rakshit, A., Singh, H.B., Eds.; Springer: Singapore,; pp. 51–79.

Ashraf, M. (2005). Pre-sowing seed treatment-A Shotgun approach to Improve Germination, Plant Growth, and Crop Yield under Saline and Non-saline Conditions. *Advance in Agronomy* 88. 223-276.

Assefa MK, Hunje R and Koti R V (2010) Enhancement of seed quality in soybean following priming treatment. *Karnataka J Agric Sci*. 23:787-89.

Astegar Z R., Sedghi M., Khomari S. (2011). Effects of Accelerated Aging on Soybean Seed Germination Indexes at Laboratory Conditions; *Not Sci Biol.*, 3(3), 126-129.

Bewley, J.D. (1997) Seed germination and dormancy. *Plant Cell,* 9, 1055–1066.

Biabani A., Boggs LC., Katozi M., Sabouri H. (2011). Effects of seed deterioration and inoculation with Mesorhizobium cicerion yield and plant performance of chickpea. *Australian Jour. of Crop Science*, 5(1), 66-70.

Bradford, K.J.; Steiner, J.J.; Trawatha, S.E. (1990) Seed priming influence on germination and emergence of pepper seed lots. *Crop Sci*., 30, 718–721.

Cantliffe, D. J. (1981, July). Priming of lettuce seed for early and uniform emergence under conditions of environmental stress. In *Symposium on Timing of Field Production of Vegetables* 122 (pp. 29-38).

Carvalho, R. F., Piotto, F. A., Schmidt, D., Peters, L. P., Monteiro, C. C., & Azevedo, R. A. (2011). Seed priming with hormones does not alleviate induced oxidative stress in maize seedlings subjected to salt stress. *Scientia Agricola*, 68, 598-602.

Chandra J, Sershen Varghese B,Keshavkant S. (2019) The potential of ROS inhibitors and hydrated storage in improving the storability of recalcitrant *Madhuca latifolia* seeds. *Seed Sci. Technol*. 47, 33–45.

Chatterjee, N., Sarkar, D., Sankar, A., Sumita, P. A. L., Singh, H. B., Singh, R. K., *et al.* (2018). On-farm seed priming interventions in agronomic crops. *Acta Agric. Slov*. 111, 715–735.

Chauhan. YS., Ghaffar. M.A., (2002). Solar heating of seeds—a low cost method to control bruchid (Callosobruchus spp.) attack during storage of pigeonpea. *Journal of Stored Products Research*, *38*(1): 87-91.

Chavan N G, Bhujbal GB and Manjare M R. (2014) Effect of seed priming on field performance and seed yield of soybean [*Glycine max* (L.) Merill] varieties. *Bioscan* 9: 111-14.

Chidananda, K. P., Chelladurai, V., Jayas, D. S., Alagusundaram, K., White, N. D. G., & Fields, P. G. (2014). Respiration of pulses stored under different storage conditions. *Journal of Stored Products Research*, 59, 42-47.

Dalil, B. (2014). Response of medicinal plants to seed priming: a review. *International Journal of Plant, Animal and Environmental Sciences*, *4*(2), 741-745.

Eskandari, H., & Kazemi, K. (2011). Effect of seed priming on germination properties and seedling establishment of cowpea (*Vigna sinensis*). *Notulae Scientia Biologicae*, 3(4), 113-116.

Farhadi R, Rahmani M R, Salehibalashahri M and Sadeghi M; (2012) The effect of Artificial ageing on germination components and seedling growth of Basil (*Ociumum basilicm* L.) seed. *Journal of Agriculture and Food Technology*, 2(4), 69-72.

Farooq M A., Ullah A, Rehman A, Nawaz A, Nadeem A, Wakeel F, Nadeem and Siddique K H M; (2018) Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. *Field Crop Res*. 216: 53–62.

Farooq, M.; Basra, S.M.A.; Afzal, I.; Khaliq, A. (2006) Optimization of hydropriming techniques for rice seed invigoration. *Seed Sci. Technol*., 34, 507–512.

Gangaraju, N., P. Balakrishna, R. Siddaraju and Parashivamurthy. (2019). Effect of Pre-Sowing Seed Treatment with Plant Growth Regulators on Crop Growth Parameters of Blackgram (*Vigna mungo* L. Hepper). *Int .J. Curr. Microbiol. App. Sci*. 8(12): 199-207.

Ghasemi-Golezani, K., Japparpour-Bonyadi, Z., Shafagh-Kolvanagh, J., & Nikpour-Rashidabad, N. (2013). Effects of water stress and hydro-priming duration on field performance of lentil. *International Journal of Farming and Allied Sciences*, 2(21), 922-925.

Ghassemi-Golezani K, Sheikhzadeh-Mosaddegh P, Valizadeh M. (2008) Effects of hydro-priming duration and limited irrigation on field performance of chickpea. *Res J Seed Sci* 1:34-40.

Ghassemi-Golezani K., A. Hosseinzadeh-Mahootchy, S. Zehtab-Salmasi, and M. Tourchi, (2012) Improving Field Performance of Aged Chickpea Seeds by Hydro-priming under water stress, *International Journal of Plant, Animal and Environmental Sciences*, 2(2), 168-176.

Ghassemi-Golezani, K., Aliloo, A. A., Valizadeh, M., & Moghaddam, M. (2008). Effects of different priming techniques on seed invigoration and seedling establishment of lentil (*Lens culinaris* Medik). *Journal of Food Agriculture and Environment*, 6(2), 222.

Ghassemi-Golezani, K., Bakhshy, J., Yaeghoob, R. A. E. Y., & Hossainzadeh-Mahootchy, A. (2010). Seed vigor and field performance of winter oilseed rape (*Brassica napus* L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 38(3), 146-150.

Gopa D, Mukherjee RK (1984) Iodine treatment of soybean and sunflower seeds for controlling deterioration. *Field Crop Res*. 9:205-213.

Gupta V and Singh M; (2012) Effect of seed priming and fungicide treatment on chickpea (*Cicer arietinum*) sown at different sowing depths in kandi belt of low altitude sub-tropical zone of Jammu. *Applied Bio Res*. 14: 187-92.

Haider M U., Farooq M., Nawaz A, and M. Hussain; (2018) Foliage applied zinc ensures better growth, yield and grain bio fortification of mungbean. *Int. J. Agric. Biol*. 20: 2817-2822.

Haider, M. U., Hussain, M., Farooq, M., & Nawaz, A. (2020). Optimizing zinc seed priming for improving the growth, yield and grain biofortification of mungbean (*Vigna radiata* (L.) wilczek). *Journal of Plant Nutrition*, 43(10), 1438-1446.

Hussain, F., Malik, A. U., Haji, M. A., & Malghani, A. L. (2011). Growth and yield response of two cultivars of mungbean (*Vigna radiata* L.) to different potassium levels. *J. Anim. Plant Sci*, 21(3), 622-625.

Ibrahim, E. A. (2016). Seed priming to alleviate salinity stress in germinating seeds. *J. Plant Physiol*. 192, 38–46.

Janmohammadi M, Moradidezfuli P; Sharifzadeh F. (2008) Seed invigoration techniques to improve germination and early growth of inbred line of maize under salinity and drought stress. *Plant physiology* 34 (3-4), 215-226.

Jyoti, Malik C.P; (2013) Seed deterioration: A review. *International journal of life sciences biotechnology and pharma research*, 2(3) 2250-

3137.

Kaisher M S, Rahman M A, Amin M H H, Ahsanullah A S M; (2010) Effects of sulphur and boron on the seed yield and protein content of mung bean. *Bangladesh research publication journal* 3:1181-6.

Kalubarmeand, S., & Madakemohekar, A. H. (2019). Study of Effect of Seed Invigoration on Seed Germination, Seedling Growth and Pod Development In Mung Bean (*Vigna radiata* L.). *Think India Journal*, 22(30), 344-348.

Khan M. U., M. Qasim, and M. Jamil (2002) Effect of different levels of zinc on the extractable zinc content of soil and chemical composition of rice; *Asian Journal of Plant Sciences* 1: 20–1

Kumar A, Sharma K D. (2009) Physiological responses and dry matter partitioning of summer mungbean (*Vigna radiata* L.) genotypes subjected to drought conditions. *Journal of Agronomy and Crop Science*, 95, 270–277.

Lin Y, Burg V D, Aartse W.J, van J.W., Zwol R.A., Jalink H. and Bino R.J. (1993) X-ray studies on changes in embryo and endosperm morphology during priming and inhibition of tomato seeds. *Seed Sci Res*. 3:171-178.

Liptay A. and Zariffa N. (1993) Testing the morphological aspects of polyethylene glycol-primed tomato seeds with proportional odds analysis. *Hort. Sci*. 28, 881-883.

Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V. G., Karthikeyan, A., and Ramalingam, J. (2020). Seed priming: a feasible strategy to enhance drought tolerance in crop plants. *Int. J. Mol. Sci*. 21, 8258.

McDonald, M. B. (1999). Seed deterioration: physiology, repair and assessment. *Seed Science and Technology*, 27(1), 177-237.

Mirmazloum I, Kiss A, Erdélyi É, Ladányi M, Németh ÉZ,Radácsi P. (2020) The effect of osmopriming on seed germination and early seedling characteristics of *Carum carvi* L. *Agriculture*. 10, 94.

Mohammadi H, Soltani A, Sadeghipour H R and Zeinali E. (2011) Effect of seed aging on subsequent seed reserve utilization and seedling growth in soybean. *Inter. Jour. of Plant Production*, 5(1), 65-70.

Moohammad E, Farzadsharif Z, Sajjad Z, Mohammad F, Mohammad D; (2012) Effect of seed priming on mung bean (*Vigna radiata*) cultivars with salicylic acid and potassium nitrate under salinity stress. *International journal of agricultural research and review*; 2: 926-932.

Nawaz H, Hussain N, Ahmed N, Rehman H, Alam J. (2021) Effeciency of seed bio priming technique for healthy mung bean productivity under terminal drought stress. *Journal of integrative agriculture* 20(1), 87-99.

Paparella, S., Araújo, S. S., Rossi, G., Wijayasinghe, M., Carbonera, D., and Balestrazzi, A. (2015). Seed priming: state of the art and new perspectives. *Plant Cell Rep*. 34, 1281–1293.

Parera, C. A., and Cantliffe, D. J. (1994). Presowing seed priming. *Hortic. Rev*. 16:109–114.

Patil, S. S., Doddagoudar, S. R., Mathad, R. C., Kurnalliker, V., & Patil, R. P. (2017). Mid storage invigouration: An attempt to extend seed vigour and viability in soybean [*Glycine max* (L.) Merill]. *Journal of Pharmacognosy and Phytochemistry*, 6(5), 1454-1459.

Rakshit, A., and Singh, H. B. (Eds.). (2018). Advances in Seed Priming. Singapore: Springer.

Rehman, H. U., Aziz, T., Farooq, M., Wakeel, A., & Rengel, Z. (2012). Zinc nutrition in rice production systems: a review. *Plant and soil*, *361*, 203-226.

Rukunudin I.H, Brn C.J, Misra M.K, Bailey T.B. (2004) Carbon dioxide evolution from fresh and preserved soybeans. *Trans. ASAE* 47, 827-833.

Sajjan AS, Dhanelappagol M S and Jolli R B. (2017) Seed quality enhancement through seed priming in pigeonpea [*Cajanus cajan* (L.) Millsp]; *Legume Research*, 40 (1), 173-177

Sarkar, D., Kar, S. K., Chattopadhyay, A., Rakshit, A., Tripathi, V. K., Dubey, P. K., *et al.* (2020). Low input sustainable agriculture: a viable climate-smart option for boosting food production in a warming world. *Ecol. Indic*. 115:106412.

Sarkar, D., Ray, S., Singh, N. K., Rakshit, A., & Singh,

H. B. (2018). Seed priming with bio-inoculants triggers nutritional enrichment in vegetables: a review. *Int. J. Agric. Environ. Biotechnol,* 736, 727-735.

Sarwar M. (2011) Effects of Zinc fertilizer application on the incidence of rice stem borers (*Scirpophaga* species) (Lepidoptera: Pyralidae) in rice (*Oryza sativa* L.) crop. *Journal of Cereals and Oilseeds* 2: 61–65.

Shelar, V. R., Shaikh, R. S., & Nikam, A. S. (2008). Soybean seed quality during storage: a review. *Agricultural Reviews*, 29(2), 125-131.

Singh, A., Dahiru, R., Musa, M., & Sani Haliru, B. (2014). Effect of Osmopriming duration on germination, emergence, and early growth of Cowpea (*Vigna unguiculata* (L.) Walp.) in the Sudan Savanna of Nigeria. *International Journal of Agronomy*, 2014(1), 841238.

Singh, H., Jassal, R. K., Kang, J. S., Sandhu, S. S., Kang, H., & Grewal, K. (2015). Seed priming techniques in field crops-A review. *Agricultural Reviews*, 36(4), 251-264.

Singh, S., Bawa, S. S., Singh, S., Sharma, S. C., & Kumar, V. (2014). Effect of seed priming with molybdenum on performance of rainfed chickpea (*Cicer arietinum* L.). *J Res Punjab Agric Univ* 51: 124-27.

Taylor, A. G., Klein, D. E., & Whitlow, T. H. (1988). SMP: solid matrix priming of seeds. *Scientia Horticulturae*, 37(1-2), 1-11.

Ullah, A., Farooq, M., Hussain, M., Ahmad, R., & Wakeel, A. (2019). Zinc seed coating improves emergence and seedling growth in desi and kabuli chickpea types but shows toxicity at higher concentration. *Int. J. Agric. Biol*. 21: 553- 559.

Varier, A., Vari, A. K., & Dadlani, M. (2010). The subcellular basis of seed priming. *Current Science*, 450-456.

Verma, J., & Srivastava, A. K. (1998). Physiological basis of salt stress resistance in pigeon pea (*Cajanus cajan* L.)-II. Pre-sowing seed soaking treatment in regulating early seedling metabolism during seed germination. *Plant Physiology And Biochemistry-New Delhi-*, 25, 89-94.

Waqas M, Korres NE, Khan MD, Nizami A, Deeba F, Ali I, Hussain H. (2019) Advances in the concept and methods of seed priming. In *Priming and Pretreatment of Seeds and Seedlings*; Hasanuzzaman, M., Fotopoulos, V., Eds.; Springer: Singapore, pp. 11–41.

Zulfiqar, F. (2021). Effect of seed priming on horticultural crops. *Scientia horticulturae*, 286, 110197.